

# SUBSURFACE AND SURFACE MICROIRRIGATION OF CORN — U.S. SOUTHERN HIGH PLAINS

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## ABSTRACT

Microirrigation has the potential to minimize application losses from droplet evaporation and drift from sprinklers, improve irrigation control with smaller, frequent applications, supply nutrients to the crop as needed, minimize deep percolation, and improve crop yields. This study was conducted to evaluate subsurface and surface microirrigation application methods on crop performance. The effects of irrigation frequency, amount, and application method on crop yield, yield components, water use, and water use efficiency of corn (*Zea mays* L.) were investigated in 1993 at Bushland, TX, on a slowly permeable soil [Pullman clay loam (fine, mixed, thermic Torric Paleustoll)] in a semi-arid environment. Irrigation frequencies were once a day and once a week; irrigation levels varied from dryland (no post emergence irrigation) to full crop water use replenishment; and application methods were on the soil surface and below ground (0.3 m) with emitters spaced 0.45 m apart and drip lines spaced 1.5 m apart. In 1993, irrigation frequency and application method did not affect crop yields; however, severe deficit irrigation (33% of full irrigation) affected crop yields by reducing the seed mass and the seed number. On the clay loam soil at Bushland, irrigation frequency and application method are less critical than proper irrigation management to avoid water deficits that affect crop yield for microirrigation systems.

**Keywords:** irrigation management, water use, water use efficiency, yield, yield components

## INTRODUCTION

The Southern High Plains region relies mainly on the Ogallala aquifer for irrigation and the highly variable rainfall to supply the majority of the irrigated crop water needs. The groundwater resource is declining in many parts of the region, and irrigation capacity (gross system flow rate per unit irrigated land area) is relatively low (4 to 11 mm/d) considering normal application losses and operational maintenance allowances. Microirrigation (Bucks and Davis, 1986) provides numerous potential advantages over other irrigation methods. Subsurface (SUB) microirrigation has been shown to enhance crop yields and reduce application losses (Phene et al., 1987). Camp et al. (1989) reported reduced corn yields for surface drip lines spaced in alternate furrows compared to surface (TOP) and SUB lines placed in the crop rows. However, Camp et al. (1993b) reported successful irrigation of vegetables with SUB lines spaced in alternate furrows (1.52 m apart). Camp et al. (1993a) reported no cotton yield difference for drip line placements in every row or in alternate furrows. Lamm et al. (1991) used alternate furrow spacing for drip lines for corn, and Lamm et al. (1992) reported that 1.5 m drip line spacing performed superior to wider drip line spacings. Irrigation frequency has been reported to affect crop performance with microirrigation (Radin et al., 1989; Davis et al., 1985; Phene et al., 1987; Caldwell et al., 1992; etc.).

The objectives of this study were to 1) evaluate SUB and TOP microirrigation methods for corn production practices in the Southern High Plains, 2) compare daily and weekly irrigation intervals for a range of water applications varying from highly deficit to fully meeting crop water use, and 3) determine the effects of the deficit irrigation regimes on crop water use and water use efficiency.

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## PROCEDURES

### Irrigation Treatments

The primary irrigation treatments were 1) irrigation frequency — daily or weekly — and 2) irrigation amount — full (T-100; complete replenishment of soil water use), medium (T-67; 2/3 of full), and low (T-33; 1/3 of full). Irrigation methods — SUB and TOP — were split plot variables. A dryland (no post-emergence irrigation) treatment (T-0) was also included. The design was a complete randomized block with split plots and three replications. Each plot was 10.7 m wide and 27.4 m long, previously laser leveled, and diked on all sides to prevent storm runoff or runoff. The total number of plots was 21 and 18 plots were split into the two method subplots. The plots were designed for 0.76 m wide rows and conventional 6-row farm equipment.

The irrigation control was based on weekly soil water measurements using a Campbell <sup>1/</sup> neutron probe (model 503DR, Campbell Pacific Nuclear Corp., Martinez, CA). The neutron probe was calibrated to the Pullman soil, and 15-s readings were taken from 0.2 m to 2.4 m deep in 0.2 m increments. The base control soil water level for irrigation scheduling was 500 mm in the 1.5 m depth ( $0.333 \text{ m}^3/\text{m}^3$ ) and was held constant throughout the experiment. The daily irrigation frequency, full amount treatment (T-100) averaged for SUB and TOP application methods was the "control treatment." The weekly irrigation amount was the difference between the measured soil water content and the control level, and then the daily irrigation amount was 1/7 of the weekly amount. The daily frequency, T-33 treatment (1/3 of full) set the low timer setting (nearest minute), and the T-67 treatment (2/3 of full) was simply 2 repeats, and the T-100 treatment was simply 3 repeats each day. The weekly treatments were then 7 repeats, 14 repeats, and 21 repeats, for the T-33, T-67, and T-100 treatments, respectively, applied in one day. If significant rain occurred (> 25 mm), the on-going daily irrigation schedule was adjusted as needed. Consequently, the daily treatments received slightly less water than the weekly treatments.

### Microirrigation Systems

The microirrigation tubing was Netafim Typhoon tubing (T25-0.6-18 Netafim Irrigation Inc., Fresno, CA) with 0.64 mm wall thickness, 0.45 m emitter spacings, and 2.3 L/h (0.6 gph) nominal emitter flow rate. Microirrigation lines were 1.52 m apart, equally spaced between two corn rows, and each plot was split with one-half irrigated by SUB at a depth of 0.3 m and by TOP. The SUB lines were permanent, and the TOP lines were designed to be removable for field operations. Figure 1 is a schematic diagram of the

microirrigation system. The alternate furrow configuration was selected as the only feasible microirrigation system for row crops in the Southern High Plains to minimize installation costs. The SUB lines were installed using Sundance chisels and reels (Arizona Drip Systems, Coolidge, AZ) mounted on a tool bar to plow three lines simultaneously. The TOP plots were also chiseled with the Sundance chisels for similarity. The SUB lines in each plot were connected to a common flush manifold. The TOP lines were connected to the plot submain with a flexible PVC hose to an above ground 50 mm PVC submain which delivered water to three laterals. The TOP lines were plugged on the ends with figure-eight loops. Each plot's submain line lead back to the control network where the three lines for a treatment were joined with a single water meter, solenoid valve, and screen filter (150 mesh). Each plot had an

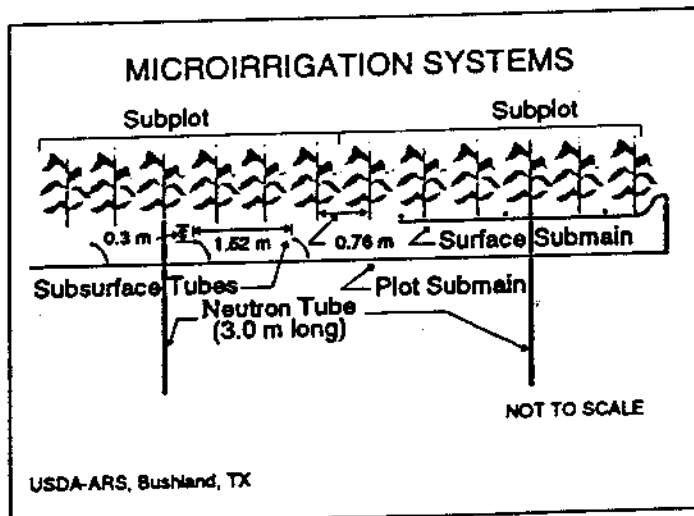


Figure 1. Schematic diagram of plot microirrigation system.

<sup>1/</sup> Mention of trade or manufacturer names is provided for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

individual 908 L/h (4 gpm) Dole Flow Control valve (Eaton Corp., Carol Stream, IL) to regulate the flow rates (a minimum pressure difference of 140 kPa was maintained across the Dole valves). Pressures at strategic points were observed periodically with dial pressure gauges. A master screen filter (100 mesh) was located before the individual treatment controls. A Rain Bird controller (MIC-8, Rain Bird Sales Inc., Glendora, CA) was used to set the operating times for each treatment. The controller was set each week to irrigate according to the need established by the soil water levels. Irrigation water was pumped from wells into a lined storage reservoir, and then a submersible turbine pump with pressure regulating tanks maintained pressure on the supply pipeline to the plots between 310 kPa and 450 kPa.

The irrigation water was treated with 13 mg(P)/kg(H<sub>2</sub>O) from phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) continuous injection (the phosphoric acid was diluted as 1:10 before injection) to serve as P nutrient source but mainly to avoid root plugging (Phene et al., 1987). Liquid Urea (28-0-0) was injected at variable concentrations from 75 mg(N)/kg(H<sub>2</sub>O) to 113 mg(N)/kg(H<sub>2</sub>O) from the six leaf stage until silking. The P and N were injected with a proportional chemical injector (Howard E. Hutchings Co., Inc., Penryn, CA) so each plot and treatment received N and P in proportion to its irrigation application.

#### Agronomic Methods

Corn (Pioneer 3245) was planted on 27 May (DOY 147) in 1993 using a 6-row planter at about 8 seeds/m<sup>2</sup> and 25 to 50 mm deep. This planting date is about one month later than optimum for this area. The delay was due to the installation of the irrigation equipment. All plots were chiseled (including the surface drip plots) and fertilized with anhydrous ammonia (NH<sub>3</sub>) at 15 g(N)/m<sup>2</sup> prior to planting. Establishment irrigations were necessary due to the dry soil conditions following the tillage operations, the "rough" field conditions following the irrigation system installation, and the lack of recent rainfall. These irrigations were applied uniformly to pre-wet the plots and for germination. The irrigation amounts were 46 mm on DOY 152, 39 mm on DOY 153, and 46 mm on DOY 154.

Grain yield was measured by hand harvesting 10 m<sup>2</sup> of area from two adjacent center rows in each subplot. The ears and plants were counted, the ears were dried at 70°C, and then hand shelled. Seed mass was determined for a 500 kernel subsample. Grain yields are expressed on a dry basis. Harvest index (ratio of grain to biomass yield on a dry basis) was measured on a separate sample of eight consecutive plants.

Water use was determined as the sum of soil water extracted from the 2.5 m soil profile and growing season rainfall and irrigations for the period after neutron tube installation to harvest. The plots were diked to prevent runoff, but profile drainage could not be determined; consequently, if drainage occurred, it would be included with the total water use values. The soil water contents at the 2.5 m depth did not change appreciably, but steady-state flow could have occurred. Water use efficiency was computed as the ratio of crop yield to water use.

## RESULTS and DISCUSSION

The corn began emerging on 2 June (DOY 154) and completed emergence by 12 June (DOY 164), and the resulting plant density was 7.4 plants/m<sup>2</sup>. The long emergence time was mainly due to the shallow planting and poor field conditions following system installation. Neutron tubes were installed to a 2.5 m depth in all plots on 15 June (DOY 166), and the first readings were taken on 16 June (DOY 167). The corn grew rapidly, tasseled on 3 August (DOY 215), and silked on 10 August (DOY 222). The corn was harvested on 14-15 October (DOYs 287 and 288). Nitrogen fertilization was stopped on 4 August (DOY 216) at silk emergence. Crop growth was normal in all respects, but somewhat taller than other corn planted earlier. Southwestern corn borers damaged the crop late in the season. The plots were aerial sprayed for insect control, but because of timing differences with other nearby corn plots, the borers seemed to do more damage in these plots. Because the yield was largely established before major problems developed, the corn borer damage was largely cosmetic, but it would have affected machine harvestable yield. The T-33 (33% soil water replenishment) treatment and the dryland check plot (T-0) suffered severe water deficits. The dryland plots were practically dead following silking, but they produced small yield amounts. Average fertilizer applications with the irrigation water were as follows:

Treatment	Nitrogen g(N)/m <sup>2</sup>	Phosphorous g(P)/m <sup>2</sup>	Irrigation mm
T-100	17	8	657
T-67	11	5	445
T-33	6	3	250
T-0	0	0	0

The nitrogen application total of 32 g(N)/m<sup>2</sup> is similar to the yield plateau level of 26 g(N)/m<sup>2</sup> reported by Lamm and Manges (1991) and their nitrogen uptake range of 28-31 g(N)/m<sup>2</sup>. Even the deficit irrigated treatments received sufficient nutrients so that fertilizer was not a limiting variable. The T-33 treatment received slightly more irrigation than design due to early controller setting errors. The weekly irrigation T-100 and T-33 treatments did receive 79 mm and 38 mm more irrigation than the daily treatments, respectively, again due to incorrect timer settings and rainfall interferences.

Irrigation applications were determined for the T-100 treatments to maintain their soil water content near this 500 mm value (about 90% of field capacity) based on the weekly neutron probe measurements (Fig. 2). The timers were set to apply the desired amounts to each treatment at the desired frequency — daily or weekly. Usually, the weekly irrigations were applied on Thursday, and the daily schedule was Wednesday through the following Tuesday. Surface microirrigations (TOP) wetted most of the area between the adjacent rows. Subsurface irrigations (SUB) wet a smaller area on the soil surface but did wet the soil surface above the drip lines. The alternate furrows, without drip lines, generally remained dry, except for rains. No detectable emitter plugging occurred for the SUB treatments since all plots maintained similar pressures.

Yield and yield component data are given in Table 1. Grain yields varied from 0.084 kg m<sup>-2</sup> for the dryland check (T-0) to 1.314 kg m<sup>-2</sup> for T-100 with the weekly frequency and TOP. SUB yield was not significantly different from the TOP yields, although the SUB grain yield was usually a little less and biomass yield a little greater than the TOP. Grain yield was affected by both kernel mass and kernel number. Plant grain yield,  $G_p$ , was linearly correlated ( $r^2 = 0.918$ ) with plant biomass yield,  $B_p$ , with the resulting regression equation:  $G_p$  (g/plant) =  $0.628 \cdot B_p$  (g/plant) - 35.6 with  $S_{y/x} = 12.2$  g/plant. Table 2 shows irrigation, water use, and water use efficiency data. Water use varied from 344 mm for the dryland check (T-0) to 956 mm for T-100 for the weekly frequency and TOP irrigation. Soil water depletion increased from a mean of 34 mm for T-100 to a mean of 112 mm for T-33.

Grain yield was related to seasonal irrigation as shown in Fig. 3. Grain yield was linearly related to water use (relationship not shown herein) up to a water use value of about 900 mm and then leveled. The drip irrigation management and application efficiency were very good resulting in almost 90% of the applied water being consumed in water use (Fig. 4). Only small amounts of applied water remained in the soil profile (above initial values), little water was lost to runoff, and both deep percolation and soil water evaporation are included in the water use values. Deep percolation was believed to be minimal because of soil physical characteristics and constant lower soil profile water

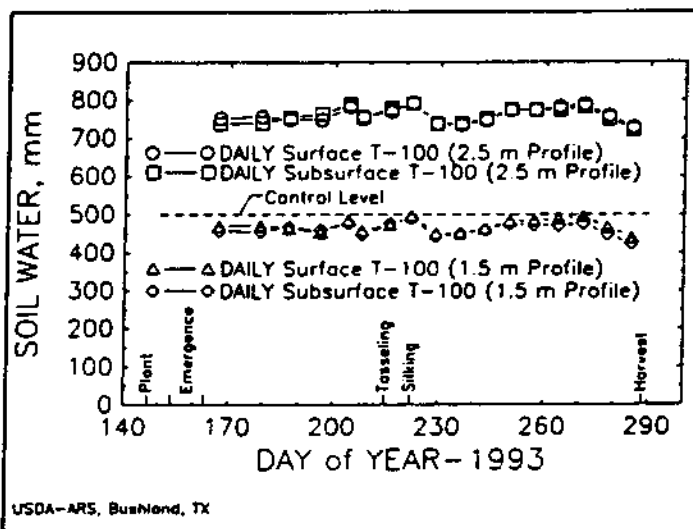


Figure 2. Soil water contents for the 2.5 and 1.5 m profile depths for the SUB and TOP T-100 daily irrigation frequency treatments. Data points are means of three replicate plots.

Table 1. Yield and yield component data.

TREATMENT			GRAIN YIELD <sup>1/</sup> kg m <sup>-2</sup>	HARVEST INDEX <sup>2/</sup> kg kg <sup>-1</sup>	BIOMASS YIELD <sup>2/</sup> kg m <sup>-2</sup>	KERNEL MASS mg kernel <sup>-1</sup>	KERNEL NUMBER # m <sup>-2</sup>
DAILY	TOP	T-100	1.240 ab <sup>2/</sup>	0.513 ab	2.60 ab	309 a	4014 abc
DAILY	SUB	T-100	1.169 abc	0.542 ab	2.97 a	317 a	3698 bcd
WEEKLY	TOP	T-100	1.314 a	0.509 ab	2.70 ab	315 a	4174 a
WEEKLY	SUB	T-100	1.307 a	0.542 ab	2.89 ab	324 a	4036 abc
DAILY	TOP	T-67	1.100 bc	0.511 ab	2.35 bcde	293 ab	3763 abcd
DAILY	SUB	T-67	1.088 c	0.488 b	2.46 abc	286 abc	3815 abc
WEEKLY	TOP	T-67	1.097 bc	0.521 ab	2.36 bcde	269 bc	4074 ab
WEEKLY	SUB	T-67	1.080 c	0.565 a	2.43 abcd	302 ab	3586 cd
DAILY	TOP	T-33	0.654 d	0.495 ab	1.60 f	228 d	2867 f
DAILY	SUB	T-33	0.666 d	0.526 ab	1.79 ef	247 cd	2699 f
WEEKLY	TOP	T-33	0.753 d	0.481 b	1.97 cdef	226 d	3343 de
WEEKLY	SUB	T-33	0.626 d	0.478 b	1.87 def	212 d	2955 ef
DRYLAND CHECK		T-0	0.084 e	0.187 c	0.65 g	147 e	577 g
LSD <sub>0.05</sub>			0.148	0.078	0.59	39	461

<sup>1/</sup> Harvest area 10 m<sup>2</sup>.

<sup>2/</sup> Harvest sample 8 plants.

<sup>3/</sup> Numbers followed by different letters are statistically different (P < 0.05) based on the least significant difference (LSD).

contents; however, steady-state drainage could have occurred. Water use efficiency (Table 2) was largely unaffected by irrigation application method or frequency for T-100 and T-67, but the deficit T-33 and T-0 treatments greatly reduced water use efficiency. However, irrigation water use efficiency  $[(Y_t - Y_d)/IRR]$ ; where  $Y_t$  is the treatment grain yield in g m<sup>-2</sup>,  $Y_d$  is the dryland yield in g m<sup>-2</sup>, and IRR is the seasonal irrigation amount in mm] increased from 2.2 kg m<sup>-3</sup> for T-100 to

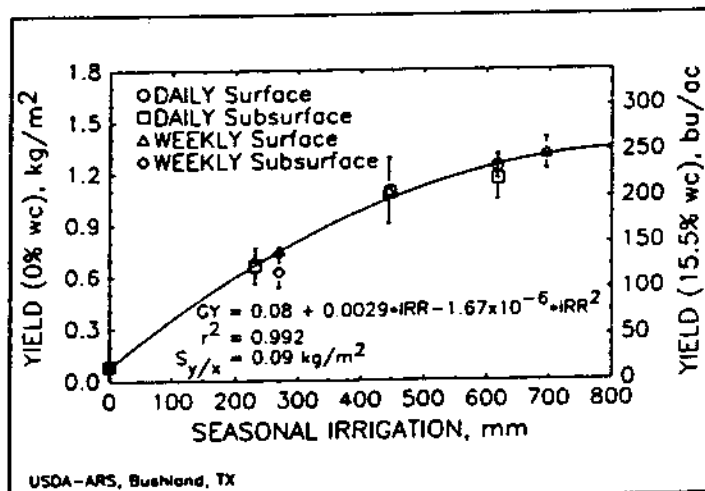


Figure 3. Corn yield response to microirrigation method, frequency, and amount in 1993 at Bushland, TX.

2.67 kg m<sup>-3</sup> for T-67 and 2.75 kg m<sup>-3</sup> for T-33. Likewise, ET water use efficiency  $[(Y_t - Y_d)/(ET_t - ET_d)]$ ; where  $ET_t$  is the treatment water use in mm and  $ET_d$  is the dryland water use in mm] increased from 1.79 kg m<sup>-3</sup> for T-100 to 2.26 kg m<sup>-3</sup> for T-67 and 2.38 kg m<sup>-3</sup> for T-33. Deficit irrigation permits greater use of rainfall and soil water thereby increasing the irrigation water use efficiency and ET water use efficiency. Although the production function illustrated in Fig. 3 has a maximum yield at an IRR (IRR<sup>\*</sup>) of 870 mm, greater marginal crop yields per unit of IRR can be realized at IRR values less than IRR<sup>\*</sup>.

Table 2. Irrigation and water use data.

TREATMENT			SEASONAL IRRIG. mm	WATER USE <sup>1/</sup> mm	WATER USE EFFICIENCY <sup>2/</sup> kg m <sup>-3</sup>	SOIL WATER DEPLETION <sup>3/</sup> mm
DAILY	TOP	T-100	617	839 b	1.48 a	23 g
DAILY	SUB	T-100	617	832 b	1.40 ab	16 g
WEEKLY	TOP	T-100	696	932 a	1.41 ab	37 fg
WEEKLY	SUB	T-100	696	956 a	1.37 ab	60 ef
DAILY	TOP	T-67	446	716 cd	1.54 a	71 fg
DAILY	SUB	T-67	446	707 cd	1.48 a	61 ef
WEEKLY	TOP	T-67	444	727 cd	1.51 a	84 cde
WEEKLY	SUB	T-67	444	738 c	1.46 a	95 bcd
DAILY	TOP	T-33	231	544 f	1.20 bc	115 ab
DAILY	SUB	T-33	231	549 f	1.21 bc	119 ab
WEEKLY	TOP	T-33	269	569 ef	1.33 ab	101 bc
WEEKLY	SUB	T-33	269	581 e	1.08 c	113 bc
DRYLAND	CHECK	T-0	0	344 g	0.24 d	144 a
LSD <sub>0.05</sub>				30	0.22	30

<sup>1/</sup> Sum of seasonal irrigation, seasonal rainfall (199 mm), and growing season 2.5-m profile soil water depletion. Assumes deep percolation and runoff were negligible. Plots were diked to minimize field runoff.

<sup>2/</sup> Ratio of grain yield to water use.

<sup>3/</sup> Measured soil water depletion over the 2.5-m profile from DOY 167 to DOY 285 by neutron attenuation.

<sup>4/</sup> Numbers followed by different letters are statistically different ( $P < 0.05$ ) based on the least significant difference (LSD).

## CONCLUSIONS

Results presented here are only for a single year, but the observed trends agree with other studies and with our initial hypotheses, except we anticipated a greater positive yield response to subsurface microirrigation. The following conclusions are drawn from the first year of this experiment, but they should be recognized to only represent a single growing season.

Microirrigation including SUB methods and alternate furrow TOP methods can be used to irrigate row crops in the Southern High Plains. Both methods were effective and efficient, but yields and water applications were not different

from an adjoining LEPA irrigated corn experiment. A major problem for microirrigation of row crops in the Southern High Plains is crop establishment. In 1993, almost 131 mm of water was necessary to insure germination and emergence of the corn. Most of this water was held in the crop rootzone and was available for later use during the growing season. This irrigation amount would be similar to that expected for a preplant irrigation using graded furrows, but the microirrigation is likely to be more evenly distributed.

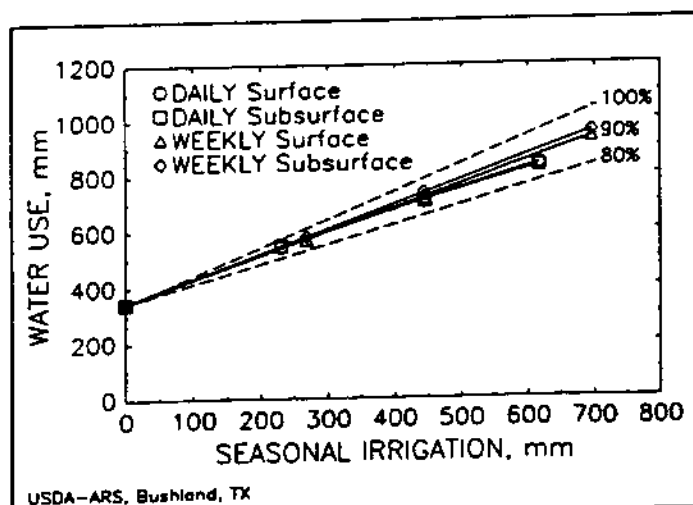


Figure 4. Water use by corn in relation to water applications by microirrigation in 1993. Dashed lines represent constant partitioning fractions of 100, 90, and 80%.

Corn yields exceeding  $1.3 \text{ kg m}^{-2}$  (245 bu/ac at 15.5 % water content) were achieved in 1993 even with the late planting date and insect problems. Water use and water use efficiency were comparable to other irrigation methods used in the Southern High Plains, although the microirrigation methods did minimize application losses thereby improving application efficiency.

Irrigation frequency on the Pullman soil did not affect corn yields as long as adequate water was applied. If soil water levels were initially low or for low water holding capacity soils, we would expect irrigation frequency to be more important. Since seasonal irrigation amount varied with irrigation frequency (largely unintentional for T-100), irrigation frequency could remain an important management variable even on soils like the Pullman series. We hope future results may be more definitive on this point. In 1993, weekly irrigations were just as effective as daily irrigations, although with weekly irrigations, storm runoff losses on 'normal' fields could be greater than for daily irrigation. The SUB method provided a drier top soil to permit rainfall storage, and even the TOP method still maintains greater than 50% of the soil surface dry for rainfall storage.

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# **Microirrigation for a Changing World:**

## **Conserving Resources/ Preserving the Environment**

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